Mathematical Tools and Representations Used By Employees of Optics and Photonics Companies

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POWER Photonics and Optics Workforce Education Research
NSF
DGE – 1432578
DUE – 1359262
R·I·T
SMERC RIT's Science and Mathematics Education Research Collaborative

Introduction

- A "math gap" exists, meaning students do not have the necessary math skills for STEM degrees and careers.
- Community colleges and universities play a crucial role in developing the skills of future employees and therefore play a pivotal role in mitigating the "skills gap."
- Higher education institutions need to know what skills are necessary for success in the workplace to better train students.
- **Goal: Determine the mathematical topics and tools technicians and engineers use in the optics and photonics workplace**

Methods

Conduct interviews with employees at Rochester, NY optics and photonics companies

Included math-specific questions in the interviews (Figure 1)

Mark all instances of math being discussed in the interviews (487 instances)

Apply emergent scheme in Table 2 to any instances labeled "Math" to classify by math type or tool

Perform inter-rater reliability with a second researcher who independently labeled the interviews to check for consistency

Apply the emergent schemes in Table 3 to instances of math types and Table 4 to instances of math tools to further explore the data

Role in Sample	Count
Engineers	14
Technicians	6
HR managers	2

Table 1: Number of participants by occupation

- **What math tasks do employees take part in daily or weekly?**
- **What tools do these tasks involve?**
- **What math skills are employees expected to use on the job?**

Figure 1: Selected questions related to math from the interview protocol

Label	Definition
Algebra	Solving equations, plug and chug, using formulas, interpreting graphs
Arithmetic	Addition, subtraction, multiplication, division, percent, counting
Calculus	Single or multivariable calculus, differential equations
Excel	Specific mention of using Excel or using a spreadsheet
Finite Element Analysis	Any mention of a finite element analysis program such as Zemax, COMSOL, Code V, LS-DYNA
Geometry and Trigonometry	Angles, shapes for design, trigonometric functions, surfaces
MATLAB	Specific mention of using MATLAB
Pencil and Paper	Any mention of doing math by hand rather than by computer or calculator

Table 2: Top-level scheme applied to every instance of math in each interview

Label	Definition
Use	Mention of how the type of math is used in the workplace
Requirement	Proficiency in the type of math is a requirement prior to employment.
Program	The math is completed in the context of a program (such as Excel)
Advantage	The type of math is not required for the job but offers an advantage in the workplace or shows mathematical aptitude
No use	Explicit mention that a type of math is not used

Table 3: Second-level scheme applied to anything labeled algebra, arithmetic, calculus, or geometry and trigonometry.

Label	Definition
Calculations	The tool is used to perform a mathematical calculation
Formulas	The tool is used to program formulas
Communication	The tool is used to communicate data or results to co-workers or customers
Analysis	The tool is used to conduct data or measurement analysis
Simulations	The tool is used to create simulations for product development/testing
Not used Primarily	Specific mention of the tool not being used to do math
Use	Specific mention of using the tool in the workplace

Table 4: Second-level scheme applied to anything labeled Excel, MATLAB, pencil and paper, or finite element analysis

Results

Top Level Code	2nd Level Code	Technicians	Engineers
Arithmetic	Use	9	2
	Requirement	4	1
Algebra	Use	2	4
	Program	4	3
	Requirement	5	4
Geometry and Trigonometry	Use	5	5
	Requirement	3	4
Calculus	Use	0	2
	No Use	5	4
	Advantage	1	2
	Requirement	0	5

Table 5: Number of interviews that were labeled with each code grouped by engineer and technician for each math type.

"We'll do touch-offs with shims for calibrating the machines, so taking the shim thickness and adding or subtracting that from tool lengths. Simple shop floor stuff like that." –Technician

"A lot of optics are equations… So a lot of them you can plug into Excel and you can solve for them…" –Engineer

"Whether it's calculating the head angle of a piece of equipment based on the radius… trig is like fundamental for everything that we're doing." -Technician

"People who have taken like Calc III, I think, where you start adding like a third dimension to the graph… they can visualized things a lot better especially with print reading…" –Technician

Top Level Code	2nd Level Code	Technicians	Engineers
Excel	Calculations	9	6
	Formulas	5	1
	Communication	2	5
MATLAB	Analysis	0	4
	Simulations	0	2
Pencil and Paper	Calculations	2	0
	Not used primarily	2	1
Finite Element Analysis	Use	0	5

Table 6: Number of interviews that were labeled with each code grouped by engineer and technician for each math tool.

"Lots of different technicians jobs, from making lens elements to assembling them to measuring them, you're collecting data and performing calculations on them. Normally it might be already set up in a workbook in Excel or something like that…" –Technician

"I do simulations in MATLAB. But most of it is just data analysis. We do moment calculations and Zernikes for wavefront." -Engineer

"[The technicians] are not doing much longhand math. They have calculators out there where they'll do some math." -Manager of Technicians

"A lot of it is software skill because we use Zemax to design the lenses, and so you have to know how to use the program to actually do what you want it to do…" –Engineer

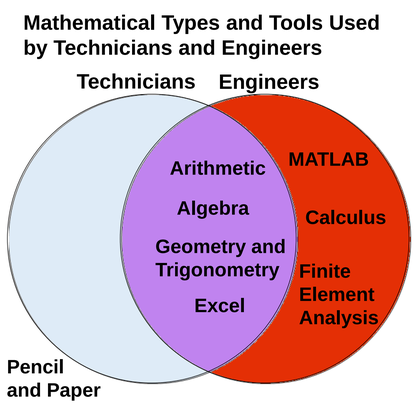

Figure 2: Venn diagram showing the mathematical types and tools used by technicians and engineers.

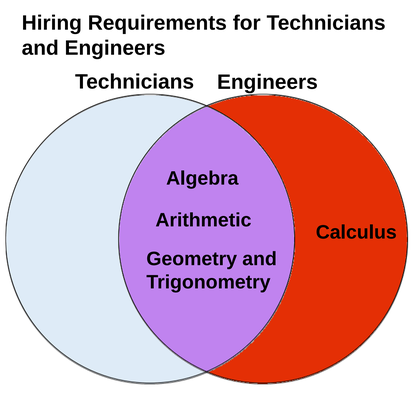

Figure 3: Venn Diagram showing the mathematical types required to be hired for technician and engineering positions.

Conclusions

Math Types

- The types of math technicians use range from arithmetic to geometry and trigonometry.
- Engineers use the same types of math as technicians, but some also use calculus.
- A significant number of engineers do not use calculus in their daily work.

Math Tools

- Technical tools such as finite element analysis software and MATLAB are used by engineers but not by technicians.
- Excel is used by both technicians and engineers.
- Engineers rarely use paper and pencil to do math.

Future Research

- Increase the number of participants interviewed to 130
- Expand our analysis to include graduate students and PhD advisors
- Compare the mathematical types and tools employees report using with those managers say their employees use

Educational Implications

- A greater emphasis should be placed on using software to aid in mathematical calculations.
- Programs like Excel and MATLAB should be taught in the undergraduate curriculum.

Acknowledgements

I would like to thank Brandon Clark, Dr. Kelly Martin, Erik Reiter, and Zackary Santos for their assistance with coding and their feedback throughout the project.